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The Relationship Between Agroeconomic Expansion and Ecosystem Quality Based on a Regression Model

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Abstract

Objective: To reveal the intrinsic relationship between agricultural economic growth and ecological environment quality in the northwest region, the study took Shaanxi, Qinghai, and Gansu as the research areas and conducted an empirical analysis of the panel data of the three provinces from 2020 to 2023. **Method:** This study utilizes the Autoregressive Integrated Moving Average model to analyze the dynamic trends of the agricultural economy, handles the cross-sectional heterogeneity of the data through the bidirectional fixed effects model, and addresses spatial dependence using the Spatial Durbin model. **Result:** The development of the agricultural economy in the northwest region has a positive effect on the quality of the ecological environment, and the degree of this effect is influenced by factors such as time and geographic location. However, the extensive economic development model will instead reduce the quality of the ecological environment. **Innovativeness:** By focusing precisely on the characteristics of arid and semi-arid regions, the reliability of the conclusion has been enhanced through the collaborative analysis of multiple models. This has verified the bidirectional influence relationship between agricultural economic development and ecological environment quality in the northwest region, providing empirical evidence for the coordinated development of the ecological economy in this type of region.

Keywords: Agricultural Economic Development; Ecological Environment Quality; Regression Model; Empirical Analysis.

1. Introduction

Agriculture, as a pillar industry of China's economy, plays a key role in ensuring food security and stabilizing farmers' income. However, resource consumption and ecological pressure in agricultural production have become increasingly serious [1, 2]. Overexploitation of farmland and the encroachment upon ecological water resources have aggravated problems such as soil degradation and wetland shrinkage. Balancing agroeconomic expansion and ecosystem quality has become an urgent issue [3, 4]. Against this background, many scholars globally have explored this topic. For instance, Fatima et al. proposed a sustainable agricultural economic development model to alleviate pressure on natural resources and the ecological environment caused by rising demand for agricultural products [5]. This study demonstrated that sustainable agricultural practices can effectively reduce greenhouse gas emissions and enhance the resilience of the ecological environment quality. However, it did not specify the exact scope of the research area, and the proposed ecological restoration plan did not account for the unique characteristics of extremely scarce water resources and limited ecological restoration capabilities in arid and semi-arid regions. Wu et al. measured the ecological efficiency of agriculture in China from 1998 to 2018 using the spatial Durbin model. The results showed that the average ecological

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efficiency of agriculture in China during this period was 0.665, indicating that the quality of the ecological environment significantly restricts the development of the agricultural economy [6]. However, the research focused on the overall level of agricultural ecological efficiency and did not analyze the heterogeneous impacts of different agricultural structures, such as dominance in planting versus animal husbandry, on ecological efficiency. Wang et al. selected 19 provinces and autonomous regions in the Yangtze and Yellow River basins as the research area and empirically analyzed the impact of integrated agricultural and tourism development on agricultural ecological efficiency. The research found that industrial integration can promote the sustainable development of the agricultural economy and the improvement of ecological environment quality [7]. However, the research only focused on the development model of the integration of agriculture and tourism, ignoring the characteristic industrial attributes of agriculture in different regions, resulting in certain limitations in the applicability of the conclusions.

In conclusion, although existing research provides support for revealing the relationship between agricultural economic development and ecological environment quality, there are still obvious research gaps. First, most studies adopt a generalized research scale, lacking targeted analysis of arid and semi-arid regions with prominent ecological vulnerabilities and failing to fully consider the constraining effect of regional resource constraints on the relationship between the agricultural economy and ecology. Second, the research perspective is relatively narrow, focusing only on the impact of agricultural economic development on the ecological environment and the ecological environment's restrictive effect on the agricultural economy and lacking in-depth exploration of the two-way interaction mechanism between the two. Third, most methods are based on a single model, and the reliability and robustness of the results need to be further verified through the combination of multiple models. The northwest region, as an arid and semi-arid area, has a weak self-repairing capacity of its ecosystem. Agricultural economic activities are much more sensitive to the ecological environment than in other regions, and the consumption intensity of water and soil resources is relatively high, resulting in a more prominent conflict between agricultural economic development and the ecological environment [8, 9]. Therefore, this study takes Shaanxi, Qinghai, and Gansu Provinces as the research area and builds the Autoregressive Integrated Moving Average (ARIMA) model and the Two-way Fixed Effects (TFE) model to empirically analyze the internal relationship between agro-economic expansion and ecosystem quality. Meanwhile, the Spatial Durbin Model (SDM) is used to account for spatial dependence beyond regional fixed effects.

The innovation points and main contributions of this study lie in the following three aspects. (1) It has broken through the limitation of the generalization of the existing research scale, precisely focusing on the three provinces of Shaanxi, Qinghai, and Gansu in the northwest region. It has fully considered the characteristics of water shortage and weak ecological restoration capacity in arid and semi-arid areas, making the conclusion more in line with the actual development needs of the region. (2) The ARIMA model is combined with the TFE model. By combining multiple models, the reliability of empirical analysis results is enhanced, effectively mitigating the potential estimation bias of a single model. (3) The SDM model is utilized to capture spatial autocorrelation and spatial spillover effects on the basis of regional fixed effects. By constructing a spatial weight matrix to quantify the mutual influence between adjacent provinces, it compensates for the limitations of traditional models in depicting spatial dependencies. (4) The empirical analysis verifies the bidirectional relationship between agricultural economic development and ecological environment quality in the northwest region, supplementing the empirical basis for the theory of the coupling of ecology and economy in arid and semi-arid regions.

This study is divided into five parts. Part 1 is the introduction, which clarifies the research background, sorts out relevant literature to identify existing research gaps, and finally explains the innovation and contribution of this study. Part 2 examines the interaction between agricultural economic development and ecological environment quality, proposes relevant hypotheses, and establishes the ARIMA and TFE models while clarifying the empirical methodology and variables. Part 3 tests the proposed hypotheses and conducts robustness and heterogeneity analyses. Part 4 discusses and summarizes the experimental data and results, comparing them with previous studies. Part 5 concludes the research, identifies its limitations, and offers suggestions for future studies.

2. Material and Methods

2.1. Theoretical Analysis and Research Hypotheses

2.1.1. Interaction Between Agro-economic Expansion and Ecological Environment

Agricultural economic development refers to a comprehensive process of transformation from a traditional extensive model to an efficient and green model, aiming to improve agricultural productivity and optimize industrial structure [10, 11]. Its core objective is to promote agricultural economic growth through resource optimization, technological progress, and institutional innovation while ensuring food security [12, 13]. Ecological environment quality is a comprehensive indicator that measures the structural integrity, functional stability, and sustainability of

regional ecosystems. It includes the self-sustaining capacity of natural ecosystems such as forests, grasslands, and rivers, as well as the coordination between human activities and ecological systems [14, 15]. There is a complex internal relationship, as shown in Figure 1.

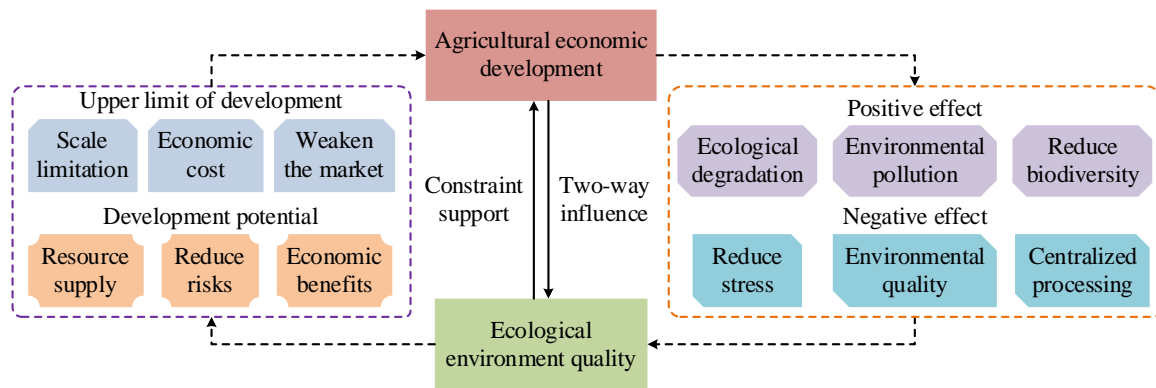


Figure 1. The internal relationship between agroeconomic expansion and ecosystem quality

As shown in Figure 1, agroeconomic expansion and ecosystem quality are coupled in a bidirectional, complex manner. Agricultural economic development can damage the ecological environment through extensive resource exploitation and excessive pollution emissions, leading to ecosystem degradation and increasing environmental burdens [16]. At the same time, it can improve ecological quality through industrial structure optimization and green transformation, which reduces resource consumption and pollution, thus producing a positive effect [17]. The core mechanism of this positive impact can be broken down into the following three aspects. The first is the innovative empowerment of agricultural technology. By promoting eco-friendly technologies such as precise fertilization and green prevention and control, the emissions of pollutants like chemical fertilizers and pesticides can be reduced while increasing the per-unit yield and quality of agricultural products, thereby achieving the dual goals of increasing production and reducing consumption. Second, improvements in irrigation efficiency have been achieved.

By installing efficient water-saving facilities, such as drip and sprinkler irrigation, to replace traditional flood irrigation, the consumption intensity of agricultural water resources has been reduced. This not only alleviates the contradiction between water supply and demand in arid and semi-arid regions but also reduces ecological problems such as wetland shrinkage and soil desertification caused by excessive water extraction. Third, large-scale and intensive operation. The development of the agricultural industrial clusters promotes the centralized allocation of production factors, facilitating the unified implementation of systematic governance such as farmland ecological protection and waste resource utilization, reducing the ecological control costs of scattered planting, and enhancing the efficiency of ecological governance. In addition, a high-quality ecological environment provides the foundation for agricultural development, as fertile soil and sufficient water resources ensure a stable supply of agricultural inputs [18]. However, as ecosystem quality declines, resource constraints, production risks, and costs increase, creating a negative cycle of ecological degradation and weakened agricultural performance.

2.1.2. Current Situation of Agricultural Development and Ecosystem Quality

The northwest region of China is the core of the arid and semi-arid zones, where ecosystems have weak self-repair capacity and are more sensitive to agricultural activities compared with eastern coastal areas [19]. The region's agriculture relies heavily on irrigation and extensive cultivation, resulting in both ecological vulnerability and agricultural dependency. Therefore, this study focuses on the three provinces of Shaanxi, Qinghai, and Gansu in Northwest China. Geographic spatial information is obtained from open-source maps, as shown in Figure 2.

As shown in Figure 2, Shaanxi, Qinghai, and Gansu are all located in Northwest China. Shaanxi and Gansu lie in the middle and upper reaches of the Yellow River, while Qinghai is an inland province in the northwest. The three provinces show different levels of agroeconomic expansion and ecosystem quality. For example, Shaanxi has strong agricultural production, with dominant industries such as apples, kiwifruit, and dairy goats. Its ecological quality continues to improve, forming a strong coupling relationship with agricultural development [20]. Qinghai has implemented a fertilizer and pesticide reduction program, reducing usage by 20.00%, which helps decrease agricultural non-point source pollution and improves soil and water quality [21]. Gansu, while developing eight major agricultural industrial clusters such as cattle, sheep, vegetables, fruits, potatoes, and grains, emphasizes water-saving practices, effectively mitigating water scarcity and improving ecosystem quality [22].

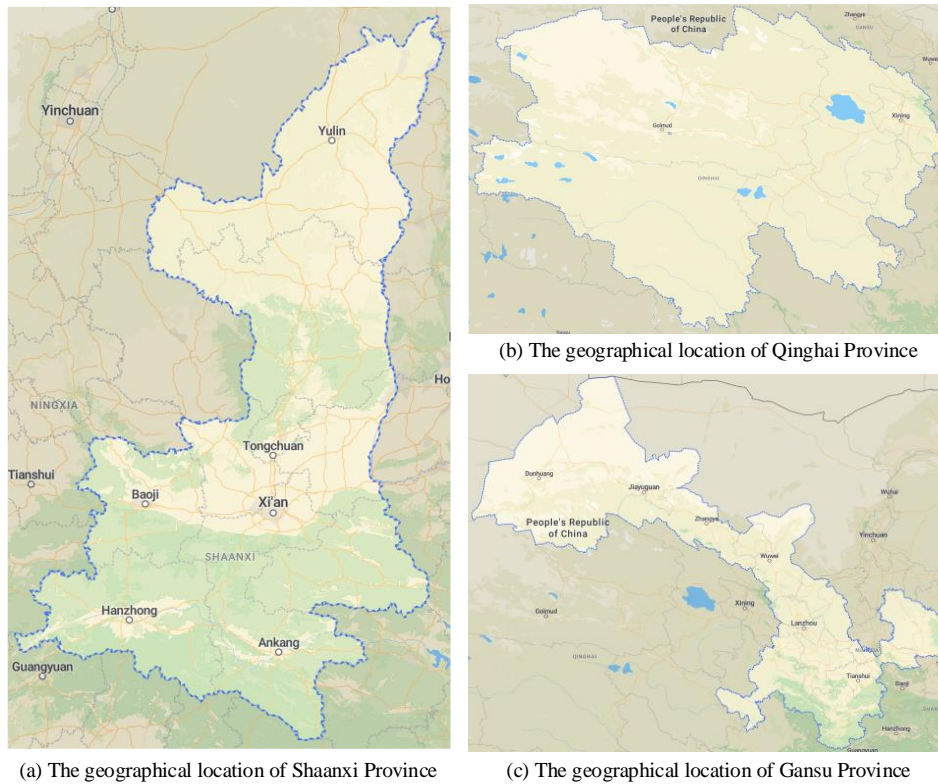


Figure 2. Geographic location of Shaanxi, Qinghai, and Gansu Provinces

2.1.3. Formulation of Research Hypotheses

Based on the above theories and current situation analysis, this study proposes the following four directional hypotheses, aiming to clarify the direction and correlation model of the interaction between agricultural economic development and ecological environment quality, rather than merely exploring the potential relationship. This is conducive to providing a clear testing framework for qualitative and quantitative analysis of the intrinsic relationship between the two in the northwest region. Hypothesis 1: There is a nonlinear relationship between agricultural economic expansion and ecosystem quality. It shows a negative impact in the early stage and a positive impact in the later stage. Hypothesis 2: An efficient and green agricultural economic development model has a significant positive effect on improving the quality of the ecological environment. An unreasonable agricultural economic development model will damage the structure and function of the ecosystem and degrade the ecological environment. Hypothesis 3: The quality of the ecological environment has a constraining effect on the development of agricultural economy. Hypothesis 4: The intensity of the impact of agricultural economic development on the quality of the ecological environment is regionally heterogeneous and is influenced by multiple factors such as geographical spatial characteristics, ecological environment background conditions, and the intensity of policy regulation.

The alignment of the proposed hypothetical framework with mature eco-economic coupling theory relies on three points. First, this study is based on the theory of coupling coordination degree. Through hypotheses 1 and 2, the coupling evolution path from conflict and imbalance to harmonious symbiosis between the agricultural economy and the ecological environment has been clarified. Second, based on the ecological carrying capacity theory, the constraint boundary and supporting role of the ecological environment on the agricultural economy were verified through Hypothesis 3. Thirdly, in combination with the theory of regional heterogeneity, Hypothesis 4 is used to reveal the differentiated manifestations of coupling relationships under different ecological background conditions. Therefore, the proposed framework not only conforms to the core logic of ecological-economic coupling theory but also concretizes and deepens the uniqueness of arid and semi-arid regions, addressing the insufficiency of empirical applications of traditional theories in such areas.

2.2. Research Methodology Design

2.2.1. Data Sources and Processing

To comprehensively analyze the impact of agro-economic expansion on ecosystem quality, this study uses panel data from Shaanxi, Qinghai, and Gansu Provinces from 2020 to 2023. The data are mainly obtained from provincial and national statistical yearbooks and open-source geographic information systems, ensuring accuracy and reliability. Specifically, agricultural data such as total agricultural output and per capita agricultural output, as well as ecological

environment indicators such as total water resources and forest coverage, are collected from the provincial and Chinese Statistical Yearbooks. Geographic data, including administrative boundaries, transportation routes, and rail networks, is obtained from open-source maps.

2.2.2. Variable Selection and Explanation

To ensure analytical accuracy, several key variables are selected, each defined and measured clearly. Detailed variable information is shown in Table 1.

Table 1. Detailed information of variables

Class	Variable	Abbreviation	Definition
Core variable	Fertilizer application rate	Far.	Indicates the total amount of chemical fertilizers applied in agricultural production
	Forest coverage rate	Fcr.	It refers to the percentage of forest area to the total land area
Control variable	Total agricultural output value	Taov.	Represent the total value of all products in agriculture, forestry, animal husbandry and fishery
	Agricultural added value	Adv.	It refers to the newly created value in agricultural production activities
	Sown area	Sa.	The area of land representing the actual sown crops in agricultural production
	Irrigated area	Ia.	It refers to the area of cultivated land that can be irrigated with a stable water source
	Rural population density	Rpd.	It refers to the ratio of the total rural population to the total land area
Other variables	Urbanization rate	Ur.	It refers to the percentage of the urban population to the total population
	Annual precipitation	Ap.	It represents the total depth of liquid water and solid water
	Average temperature	At.	It is a meteorological indicator that affects the growth of crops

As shown in Table 1, fertilizer application and forest coverage rate are used as core variables, while total agricultural output, per capita agricultural output, and cultivated area are control variables. Annual precipitation and average temperature are used as additional variables. Fertilizer application refers to the total amount of chemical fertilizers used in agricultural production within a region and serves as a key indicator for agricultural non-point source pollution pressure. Forest coverage rate represents the percentage of forest area to total land area and reflects water and soil conservation capacity and biodiversity of the ecosystem. To avoid randomness in the empirical results, several control variables—such as total agricultural output, per capita agricultural output, cultivated area, and rural population density—are included. Annual precipitation and average temperature further constrain the control variables. Based on these data, the study conducts empirical analysis on the relationship between agro-economic expansion and ecosystem quality in Shaanxi, Qinghai, and Gansu.

2.2.3. Construction of Analytical Models

The ARIMA model is a time series forecasting method used to analyze dynamic patterns of single-variable data and predict future trends [23, 24]. Therefore, an ARIMA model is constructed to analyze agricultural economic and ecological environment data from multiple years in each province. Its functional expression is shown in Equation 1.

$$\nabla^d y_t = c + \sum_{p=1}^p \phi_p \nabla^d y_{t-p} + \tau_t - \sum_{q=1}^q \theta_q \tau_{t-q} \tag{1}$$

In Equation 1, $\nabla^d y_t$ represents the time series after d differences in year t . c is a constant term. p and q represent the orders of autoregressive and moving average terms, respectively. ϕ_p and θ_q are their coefficients, and τ_t is the random error term. The TFE model controls both individual and time fixed effects, allowing the identification of the net effect of key independent variables on dependent variables while avoiding estimation bias caused by regional or temporal factors [25]. Thus, a TFE model is constructed to compare the commonalities and differences of the agricultural economy–ecological environment relationship among Shaanxi, Qinghai, and Gansu and to test the net effect of agro-economic expansion on ecosystem quality. The functional form of the TFE model is shown in Equation 2.

$$E_{it} = \beta_0 + \beta_1 \cdot Q_{it} + \gamma \cdot X_{it} + \mu_i + \lambda_t + \varepsilon_{it} \tag{2}$$

In Equation 2, E_{it} represents the ecosystem quality index of province i in year t . Q_{it} is the agro-economic expansion index of province i in year t , with β_1 as its coefficient. X_{it} is the vector of control variables, γ is its coefficient, μ_i and λ_t denote individual and time fixed effects, and ε_{it} is the random error term. Meanwhile, to address the issue of spatial dependence, this study introduces the SDM model on the basis of the TFE model. This model can not only capture the spatial autocorrelation of the dependent variable but also take into account the spatial spillover effect of the independent variable. It can comprehensively depict the interdependent relationship in geographic space on the basis of controlling for the fixed effect of the region.

In addition, the integration process of the model results is as follows: Firstly, the ARIMA model is used to obtain the temporal trends and short-term fluctuation characteristics of agricultural economic development and ecological environment quality in each province, in order to identify the dynamic correlation between the two in the temporal dimension and provide a basic conclusion in the temporal dimension for subsequent cross-sectional analysis. Then, the TFE model was utilized to separate the time-fixed effect, focusing on the heterogeneity of Shaanxi, Qinghai, and Gansu provinces in terms of geographical space, industrial structure, etc., in order to quantify the differences in the net effect of agricultural economic development on ecological environment quality in different regions. Finally, the time dynamic coefficients obtained from the ARIMA model and the cross-sectional heterogeneity coefficients of the TFE model were co-verified. If the two are consistent in the direction of the influence of the core variables, it proves the reliability of the conclusion. If there are phased differences, cross-interpretation is carried out in combination with the time trend and regional characteristics to clarify the causes of the differences.

2.2.4. Multicollinearity and Endogeneity Tests

Before the regression analysis, in order to avoid estimation bias caused by multicollinearity among independent variables, the Variance Inflation Factor (VIF) was used to test all independent variables in the study. The results show that the VIF values of all variables range from 1.23 to 3.47, which is much lower than the critical value of 10. The average VIF value is 2.15. This indicates that there is no serious multicollinearity problem among the independent variables. There is no need to adjust the model structure by eliminating variables or other means, and it can be directly used for regression analysis.

Meanwhile, the study took the total power of agricultural machinery (Tpam.) and the proportion of agricultural research funds input (Piarf.) as instrumental variables and adopted the instrumental variable method to test the possible endogeneity problems between agricultural economic development and ecological environment quality. The results are shown in Table 2.

Table 2. Endogeneity test results table

Variable name	First stage (Taov.)	First stage (Adv.)	Second stage (Ecological environment quality)
Tpam.	0.627***(8.35)	0.584***(7.92)	-
Piarf.	0.473***(6.29)	0.436***(5.87)	-
Taov.	-	-	0.912***(9.85)
Adv.	-	-	0.826***(7.66)
Sa.	-	-	0.791**(6.50)
Ia.	-	-	0.662*(4.72)
Rpd.	-	-	0.605*(5.11)
Ur.	-	-	-0.734***(-7.43)
F-statistic	36.82	34.15	-
χ^2/p	-	-	28.36/0.002
R ²	0.81	0.78	0.85

As can be seen from Table 2, the study first determines whether the model has endogeneity through the Hausman Test. The test statistic $\chi^2=28.36, p=0.002$. The null hypothesis that all explanatory variables are exogenous was rejected, indicating that the model has an endogeneity problem. Then, the two-stage least squares method (2SLS) was used to re-estimate the model. The regression results of the first stage showed that the regression coefficient of the instrumental variable with respect to the core explanatory variable was significantly positive ($p<0.01$), and the F-statistic of the weak instrumental variable test was 36.82, indicating that the instrumental variable was effective. In the regression results of the second stage, the coefficient signs of the core variables were consistent with those of the benchmark regression, and the significance level remained stable, indicating that the conclusion was still reliable after controlling for endogeneity.

2.3. Data Analysis Methods

To comprehensively and accurately examine the complex relationship between agroecomic expansion and ecosystem quality in Shaanxi, Qinghai, and Gansu Provinces, this paper employs descriptive statistical analysis, correlation analysis, and benchmark regression analysis to conduct an empirical investigation. In addition, heterogeneity analysis and robustness tests are applied to verify the accuracy, stability, and reliability of the results, ensuring the validity of the findings.

3. Results

3.1. Descriptive Statistical Analysis

To gain a clearer understanding of the selected variables, the study conducted a descriptive statistical analysis on the panel data of several key variables from Shaanxi, Qinghai, and Gansu Provinces and used the average values as the final results. The outcomes were shown in Table 3.

Table 3. Descriptive analysis of key variables

Variable	Shaanxi (Mean value)	Qinghai (Mean value)	Gansu (Mean value)	Standard deviation
Taov. (billion yuan)	315.532	22.275	171.377	123.958
Adv. (billion yuan)	191.270	36.908	146.765	79.319
Sa. (thousand hectares)	3011.46	585.07	4037.13	1772.43
Ia. (thousand hectares)	1254.10	220.63	1362.60	633.15
Rpd. (thousand hectares)	4795.64	4053.36	2207.05	1329.28
Ur. (%)	63.87	61.33	53.81	5.06

As shown in Table 3, from 2020 to 2023, the average total agricultural output values of Shaanxi, Qinghai, and Gansu were 315.532 billion yuan, 22.275 billion yuan, and 171.377 billion yuan, respectively, with a standard deviation of 123.958. The large standard deviation indicates that the gap in the scale of the agricultural economy among the three provinces is relatively significant. This gap is the result of the combined effect of multiple factors, such as natural conditions and industrial foundations, in the three provinces. Shaanxi showed higher averages than Qinghai and Gansu in total agricultural output, agricultural added value, population density, and urbanization rate. Gansu had the highest averages in sown area and irrigated area, reaching 4037.13 thousand hectares and 1362.60 thousand hectares, respectively. Constrained by natural conditions such as plateau terrain and cold climate, Qinghai's agricultural production mainly relies on animal husbandry. The cultivated land resources are scarce and scattered, and the population density is low. As a result, both the scale of the agricultural economy and the intensity of resource utilization are at a relatively low level. Consequently, the average values across all variables are the lowest. These results indicated significant regional heterogeneity in the agro-economic expansion of the three provinces. Shaanxi, supported by higher population density and urbanization rate, achieved stronger performance in economic indicators such as total agricultural output and agricultural added value. Gansu, relying on cultivated land resources, had the largest scale of land utilization with its extensive sown and irrigated areas. In contrast, Qinghai's high-altitude terrain, sparse population, and livestock-oriented industrial structure resulted in relatively low levels of agricultural economic activity and resource utilization.

3.2. Correlation Analysis

After obtaining a preliminary understanding of the variables, the study performed a correlation analysis among several major variables to reveal their interrelationships. The specific results were presented in Table 4.

Table 4. Correlation coefficients among main variables

Variable	Far. (T)	Fcr. (%)	Taov. (100 million yuan)	Sa. (thousand hectares)	Rpd. (Person per thousand hectares)	Ur. (%)
Far. (T)	1.000	-0.428***	0.643***	0.721***	0.462***	-0.524***
Fcr. (%)	-0.428***	1.000	-0.274**	-0.365**	-0.437***	0.408***
Taov. (100 million yuan)	0.643***	-0.274**	1.000	0.861***	0.535***	-0.649***
Sa. (thousand hectares)	0.721***	-0.365**	0.861***	1.000	0.584***	-0.607***
Rpd. (Person per thousand hectares)	0.462***	-0.437***	0.535***	0.584***	1.000	-0.835***
Ur. (%)	-0.524***	0.408***	-0.649***	-0.607***	-0.835***	1.000

Note: *, **, *** indicate significance at the significance levels of 10.00%, 5.00%, and 1.00%.

As shown in Table 4, the correlation coefficients between fertilizer use and forest coverage rate, as well as urbanization rate, were -0.428 and -0.524, both significant at the 1.00% level. In contrast, fertilizer use was positively correlated with total agricultural output (0.643) and sown area (0.721), both statistically significant. This reflects that agricultural production in the northwest region still relies partially on chemical fertilizer input at present, and the expansion of sown area often increases the use of chemical fertilizers. This correlation reflects the path dependence of the traditional agricultural production model. To visualize these relationships, a heatmap of the correlations among the main variables was drawn, as shown in Figure 3.

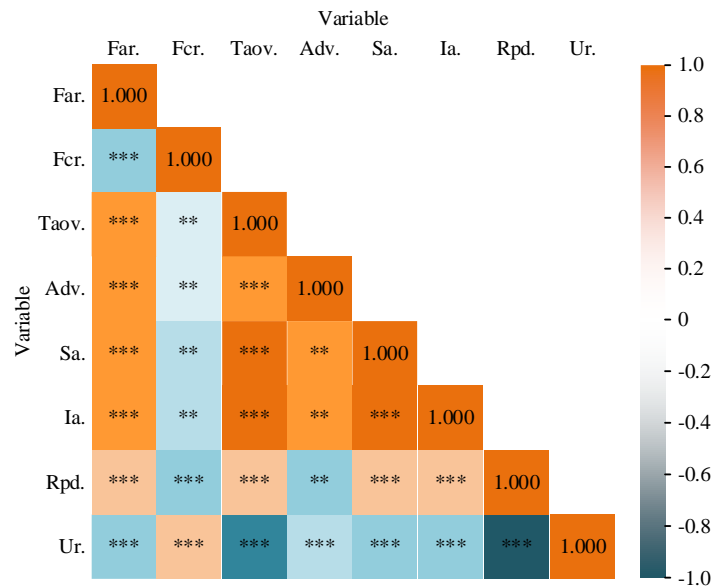


Figure 3. Correlation heat map between variables

Figure 3 illustrated that the correlation coefficients between forest coverage rate and rural population density, and between forest coverage rate and urbanization rate, were -0.401 and 0.408, respectively—the former negative, the latter positive. This is because the higher the rural population density, the greater the intensity of land resource development, and the more likely it is to lead to a decline in forest coverage. The increase in the urbanization rate can generate a population agglomeration effect, thereby alleviating the ecological carrying pressure on rural areas and creating conditions for forest restoration. Combining the results from Table 3 and Figure 3, it was evident that intensive rural economic activities occupied forest space, increasing environmental pressure. However, as urbanization advanced and rural populations migrated, ecological pressure gradually eased, supporting Hypothesis 1. Overall, the correlation analysis results confirmed that agroeconomic expansion and ecosystem quality were closely linked.

3.3. Benchmark Regression Analysis

The study further used the constructed ARIMA model and TFE model to conduct regression analyses on the relationship between agroeconomic expansion and ecosystem quality in Shaanxi, Qinghai, and Gansu Provinces, with the average values taken as final results. The independent variables included total agricultural output, agricultural added value, sown area, irrigated area, rural population density, and urbanization rate, while the dependent variable was ecosystem quality. The results were shown in Table 5.

Table 5. Benchmark regression analysis results

Independent variable	Coefficient	Standard error	t	p
Taov.	0.942***	0.005	10.37	0.003
Adv.	0.836***	0.021	8.15	0.006
Sa.	0.801**	0.029	6.76	0.009
Ia.	0.679*	0.035	4.91	0.010
Rpd.	0.612*	0.022	5.28	0.012
Ur.	-0.745***	0.014	-7.56	0.007
R ²	0.88	-	-	-

As presented in Table 5, total agricultural output and agricultural added value were positively and significantly correlated with ecosystem quality, with regression coefficients of 0.942 and 0.836, both significant at the 1.00% level. This indicated that agroeconomic expansion in Northwest China had moved beyond the stage of extensive, ecologically damaging expansion and had entered a phase that positively contributed to ecological improvement, supporting Hypothesis 1. The coefficients of sown area, irrigated area, and rural population density were 0.801, 0.679, and 0.612, significant at the 5.00% and 10.00% levels, respectively. These results showed that the expansion of cultivated areas and the improvement of irrigation facilities in Northwest China were carried out under scientific planning, enabling coordinated development between economic growth and ecological protection, verifying Hypothesis 2. In contrast, the

coefficient of urbanization rate was -0.745, indicating a negative relationship with ecosystem quality. This suggested that infrastructure expansion driven by urbanization possibly occupied farmland and forest areas, leading to ecological degradation alongside agricultural economic growth, also verifying Hypothesis 2. To further visualize the relationship between agroeconomic expansion and ecosystem quality in Shaanxi, Qinghai, and Gansu, the study presented changes in fertilizer use and forest coverage rates from 2018 to 2023, as shown in Figure 4.

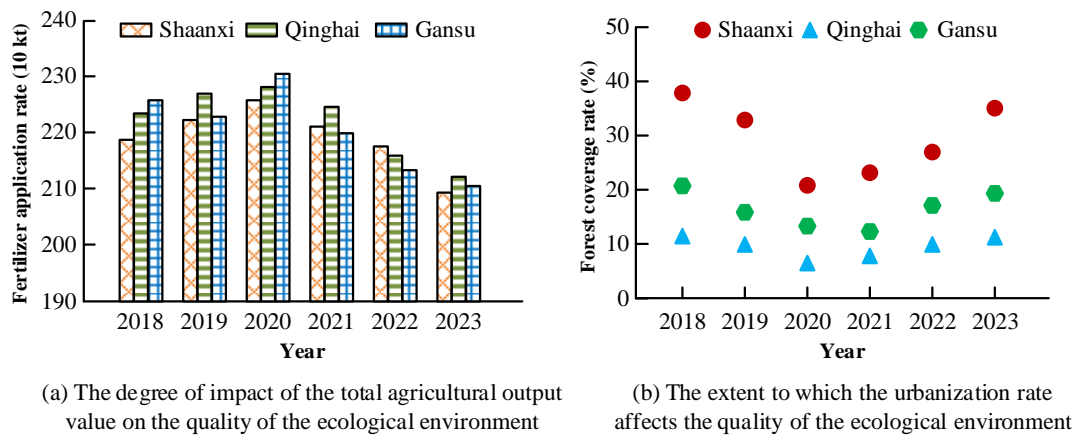


Figure 4. Changes in fertilizer application and forest coverage

Figure 4(a) showed that fertilizer use in all three provinces first increased and then decreased, peaking in 2020 at 2.254 million tons, 2.276 million tons, and 2.301 million tons, respectively. This pattern aligned with the typical process where ecological quality initially declined during rapid agricultural expansion and improved later with the implementation of ecological restoration measures. Figure 4(b) revealed that forest coverage rates in the three provinces first declined and then increased, with Shaanxi experiencing the largest decrease from 38.14% to 20.08% between 2018 and 2020. This was mainly due to the earlier extensive agricultural expansion damaging forest ecosystems, followed by a shift toward green agricultural development and ecological protection policies that restored forest ecology—further confirming Hypotheses 1 and 2. To explore spatial differences in the impact of agroeconomic expansion on ecosystem quality, the study introduced regional control variables into the regression model and conducted another benchmark regression analysis. The results were shown in Table 6.

Table 6. Analysis results after adding regional control variables

Independent variable	Coefficient	Standard error	t	p
Taov.	0.927***	0.004	10.05	0.003
Adv.	0.852***	0.019	8.30	0.006
Sa.	0.784**	0.030	6.87	0.009
Ia.	0.628*	0.037	4.64	0.013
Rpd.	0.635*	0.020	5.46	0.010
Ur.	-0.701***	0.016	-7.92	0.009
Regional fixed effect	Controls	-	-	-
R ²	0.84	-	-	-

In Table 6, after adding regional control variables, the coefficient of total agricultural output decreased from 0.942 to 0.927, sown area declined from 0.801 to 0.784, and irrigated area dropped by 0.051. The decline in the coefficient of total agricultural output value indicates that regional characteristics have a slight inhibitory effect on the relationship between the agricultural economy and the ecological environment. The natural and social conditions of different regions will affect the intensity of the effect of agricultural production on the ecological environment. Although the coefficients of these three variables decreased slightly, their correlations and significance levels remained stable, still showing positive associations with ecosystem quality at the 1.00% and 10.00% significance levels. This demonstrated that the positive effects of these variables on ecosystem quality were robust, verifying Hypotheses 1 and 2 once again. Meanwhile, the regression coefficients of agricultural added value, rural population density, and urbanization rate increased by 0.016, 0.023, and 0.044, respectively, suggesting that regional characteristics strengthened both the positive and negative impacts of these factors on ecosystem quality, thereby supporting Hypothesis 4.

3.4. Heterogeneity Analysis

To further analyze the impact of agroecomic expansion on ecosystem quality in Northwest China, the study conducted a heterogeneity analysis. Using Shaanxi, Qinghai, and Gansu as representative regions, regression analyses were carried out for each province to explore the spatial differences in the relationship between agroecomic expansion and ecosystem quality. The results were shown in Table 7.

Table 7. Heterogeneity analysis results of Shaanxi, Qinghai, and Gansu provinces

Variable	Shaanxi	Qinghai	Gansu
Taov.	0.953*** (10.91)	0.922*** (9.84)	0.951*** (10.36)
Adv.	0.856*** (8.42)	0.809*** (7.90)	0.843*** (8.22)
Sa.	0.816** (6.89)	0.785** (6.63)	0.802** (6.76)
Ia.	0.687* (4.93)	0.658* (4.72)	0.692* (5.08)
Rpd.	0.625* (5.54)	0.601* (5.06)	0.610* (5.24)
Ur.	-0.732*** (-7.40)	-0.767*** (-7.72)	-0.736*** (-7.56)
R ²	0.90	0.86	0.88

As shown in Table 7, the regression coefficients of total agricultural output in Shaanxi and Gansu were 0.953 and 0.951, respectively, which were 0.011 and 0.009 higher than the average value, while that of Qinghai was 0.922, lower than the average. In addition, the coefficients of agricultural added value, sown area, and irrigated area in Shaanxi and Gansu were all higher than the average, and each was significant at different levels. In contrast, all corresponding coefficients in Qinghai were below the average. These results indicated that under different ecological constraints and policy environments, the effects of agroecomic expansion on ecosystem quality varied across the Northwest region. Specifically, agroecomic expansion in Shaanxi and Gansu had stronger positive effects on ecosystem quality than the regional average, while Qinghai's effects were weaker, which supported Hypothesis 4. The study then extended the panel data of the three provinces to cover 2014–2023 and conducted another heterogeneity analysis. The results were presented in Table 8.

Table 8. Analysis results considering the time dimension

Variable	Shaanxi	Qinghai	Gansu
Taov.	0.984*** (12.37)	0.952*** (11.89)	0.939*** (11.44)
Adv.	0.862*** (9.04)	0.841*** (8.76)	0.885*** (9.23)
Sa.	0.786** (6.79)	0.814** (7.05)	0.827** (7.21)
Ia.	0.702* (5.74)	0.681* (5.33)	0.694* (5.51)
Rpd.	0.630* (5.23)	0.588* (4.67)	0.619* (5.10)
Ur.	-0.720*** (-8.13)	-0.734*** (-7.82)	-0.715*** (-8.18)
R ²	0.87	0.85	0.86

As shown in Table 8, after expanding the time dimension to nearly ten years, the regression coefficient of total agricultural output in Shaanxi increased to 0.984, 0.042 higher than the average in Table 4, representing an increase of 0.045. Although Qinghai remained significant at the 1.00% level, its coefficient only increased by 0.010. By contrast, Gansu's coefficient declined slightly from 0.942 to 0.939. These results suggested that Shaanxi improved the adaptability of its agricultural economy to the ecological environment through technological upgrades such as water-saving irrigation, efficient fertilizer use, and industrial structure optimization. Qinghai's agricultural economy remained dominated by plateau animal husbandry with limited crop cultivation, maintaining a balance within ecological constraints. Gansu's agricultural development, however, was restricted by water scarcity and soil degradation, which slowed its green transition and highlighted the need to further enhance the compatibility between agriculture and the ecological environment, verifying Hypothesis 3. To visualize how ecosystem quality constrained agroecomic expansion in Northwest China, the study used the ARIMA model to predict the trends of economic crop proportion and agricultural output proportion as water resource utilization rate changed. The results were shown in Figure 5.

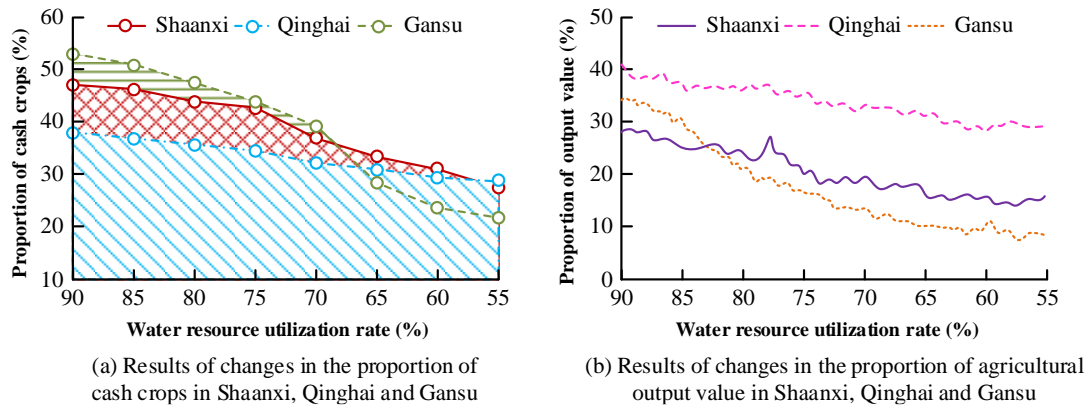


Figure 5. Changes in crop and output value ratios with utilization rates

Figure 5(a) showed that when water resource utilization decreased from 90.00% to 55.00%, the proportion of economic crops declined sharply in all three provinces. In Gansu, the proportion dropped from 53.16% to 22.04%, a decrease of 31.12%. As shown in Figure 5(b), the proportion of agricultural output also declined as water resource utilization decreased. Gansu experienced the most significant drop, with a decrease of 26.75%, followed by Qinghai with 15.31%, and Shaanxi with 11.93%. These results demonstrated that due to Gansu's severe water shortage—where agricultural water accounted for over 80.00% of total usage—reductions in water resource utilization had stronger effects on both the proportion of economic crops and agricultural output. This finding further verified Hypothesis 3. Overall, the results indicated that agroeconomic expansion in Shaanxi, Qinghai, and Gansu initially degraded ecosystem quality during the early stages but improved it during the transition toward efficient and green development, suggesting a bidirectional relationship between agroeconomic expansion and ecosystem quality in Northwest China.

3.5. Robustness Test

To ensure the reliability and accuracy of the above analyses, the study conducted robustness tests using three estimation methods: the method of moments, ridge regression, and ordinary least squares. The results were shown in Table 9.

Table 9. Test results of three methods

Variable	Moment estimation	Ridge regression	Ordinary least square
Taov.	0.941*** (11.07)	0.908*** (10.36)	0.925*** (10.67)
Adv.	0.835*** (8.42)	0.859*** (8.60)	0.864*** (8.79)
Sa.	0.796** (7.25)	0.780** (6.87)	0.786** (7.04)
Ia.	0.658* (5.14)	0.637* (4.96)	0.665* (5.22)
Rpd.	0.650* (5.59)	0.672* (5.85)	0.657* (5.71)
Ur.	-0.696*** (-8.05)	-0.714*** (-8.52)	-0.728*** (-8.83)
Regional fixed effect	Controls	Controls	Controls
Time-fixed effect	Controls	Controls	Controls
R ²	0.87	0.91	0.88

In Table 9, although slight differences existed among the coefficients of variables such as total agricultural output, sown area, and rural population density under the three estimation methods, the coefficients of total agricultural output, agricultural added value, and urbanization rate remained significant at the 1.00% level. Meanwhile, the coefficients of sown area, irrigated area, and rural population density showed stable correlations and significance at the 10.00% and 5.00% levels, respectively. The coefficient differences among the three estimation methods mainly stem from the statistical characteristics of the different estimation methods. The moment estimation method pays more attention to solving the endogeneity problem, ridge regression can effectively handle multicollinearity, and the ordinary least squares rule is the basic estimation method. The significance of the core variables remains consistent under the three methods, indicating that the conclusion is not affected by the choice of estimation methods. Finally, the study replaced irrigated area and rural population density with annual precipitation and average temperature and conducted another regression analysis. The results were presented in Table 10.

Table 10. Analysis results after replacing variables

Variable	Coefficient	Standard error	t	p
Taov.	0.956***	0.007	10.72	0.004
Adv.	0.824***	0.019	8.01	0.008
Sa.	0.813**	0.033	6.94	0.008
Ap.	0.345**	0.026	9.03	0.011
At.	0.130**	0.024	2.40	0.015
Ur.	-0.725***	0.017	-7.35	0.009
R ²	0.87	-	-	-

As shown in Table 10, when the variables were replaced with annual precipitation and average temperature, their mean coefficients were 0.345 and 0.130, both significant at the 5.00% level and positively correlated with ecosystem quality. This is because an increase in annual precipitation can improve soil moisture, enhance vegetation coverage, and provide water support for the restoration of the ecosystem. Meanwhile, an appropriate average temperature is conducive to the growth of crops and the stability of ecosystem functions. Therefore, both have a positive impact on the quality of the ecological environment. Moreover, the coefficient of total agricultural output increased to 0.956, while that of agricultural added value decreased to 0.824. The coefficients of sown area and urbanization rate changed to 0.813 and -0.725, respectively, with their significance levels remaining stable. This indicates that the relationship between the core explanatory variable and the explained variable is stable. After replacing the control variable, the positive effect of agricultural economic development on the quality of the ecological environment and the negative effect of urbanization remain significant, effectively verifying the reliability of the conclusion. To illustrate the effects of annual precipitation and average temperature on ecosystem quality, the study used the Ecological Quality Index (EQI) as the dependent variable and annual precipitation and average temperature as independent variables. The ARIMA model simulated the trends of EQI with changes in these two factors, as shown in Figure 6.

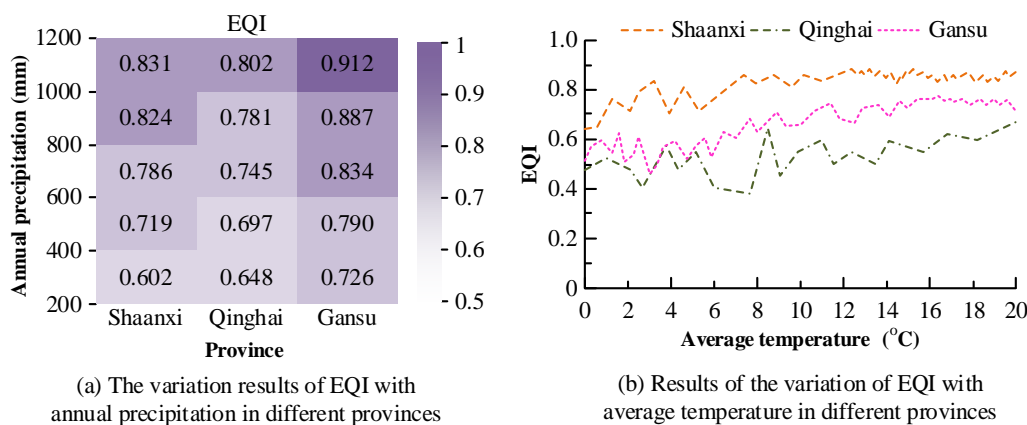


Figure 6. Comparison of EQI changes with annual precipitation and average temperature

Figure 6(a) showed that when annual precipitation reached 200 mm, the EQI values of all three provinces were above 0.6 and increased with higher precipitation. In Gansu, where agriculture was mainly developed in arid and semi-arid areas, precipitation was the key factor influencing vegetation cover, soil moisture retention, and hydrological cycles. Therefore, the EQI in Gansu increased most rapidly with rising precipitation, reaching as high as 0.912 at 1200 mm, far exceeding that of Shaanxi and Qinghai. Figure 6(b) showed that as the average temperature rose, the EQI values of the three provinces generally increased with some fluctuations. When the average temperature increased from 0°C to 20°C, the mean EQI values of Shaanxi, Qinghai, and Gansu were 0.813, 0.647, and 0.560, respectively. In summary, there was a significant bidirectional relationship between agroeconomic expansion and ecosystem quality in Shaanxi, Qinghai, and Gansu. Intensive, green-oriented agricultural development helped improve ecosystem quality, while ecological conditions, in turn, constrained agricultural economic growth. The effects of agroeconomic expansion on ecosystem quality were also influenced by multiple factors, including geographical and ecological conditions.

4. Discussion

Based on panel data from Shaanxi, Qinghai, and Gansu Provinces from 2020 to 2023, this study used the ARIMA and TFE models to examine the relationship between the agroeconomic expansion and the ecosystem quality in Northwest China. The results of heterogeneity analysis and robustness tests further confirmed the reliability of the findings. The study found that variables highly related to agroeconomic expansion, such as total agricultural output value and agricultural added value, showed a strong positive correlation with ecosystem quality. The regression

coefficients of total agricultural output value and agricultural added value were 0.942 and 0.836, respectively, both significant at the 1.00% level. These results were consistent with the findings of Raihan et al. [26], who examined the effect of agro-economic expansion on carbon dioxide emissions. Raihan et al. [26] took India as the research object and found that through technological progress and industrial structure optimization, the agricultural economy has reduced the carbon emission intensity per unit output, which is consistent with this study's core conclusion that the development of the agricultural economy has a positive impact on the ecological environment, confirming the universal law of the coordinated development of the ecological economy. However, there are differences in research scenarios between the two. As a densely populated agricultural country, India faces significant ecological pressure on agriculture, mainly from the excessive use of chemical fertilizers and pesticides in large-scale farming. In contrast, the core constraints in the northwest region are water shortage and ecological vulnerability.

Therefore, this study further highlights the key role of water-saving technologies and ecologically adapted industrial structures in arid and semi-arid regions. Meanwhile, the coefficients of sown area, irrigated area, and rural population density were 0.801, 0.679, and 0.612, respectively, significant at the 5.00% and 10.00% levels. The coefficient of urbanization rate was -0.745, indicating a significant negative correlation with ecosystem quality. Similarly, Hardi et al. [27] found that agricultural productivity in Indonesia had a positive effect on greenhouse gas emissions, while greenhouse gas emissions constrained agricultural economic growth, findings that were in line with this study. This study found that improvements in agricultural productivity have a positive inhibitory effect on greenhouse gas emissions, but land development during urbanization will aggravate ecological damage, which aligns with the negative impact of the urbanization rate observed in the study. However, the difference lies in the fact that the ecological pressure from urbanization in Indonesia mainly stems from deforestation of tropical rainforests, whereas in the northwest region it stems from the encroachment of cultivated and forest land and the excessive exploitation of water resources. This difference indicates that the relationship between the agricultural economy and the ecological environment has a significant regional dependence.

The heterogeneity analysis showed that the impact of the agricultural economy on ecosystem quality was strongest in Shaanxi, followed by Gansu, and weakest in Qinghai. The coefficients of total agricultural output value in these provinces were 0.953, 0.951, and 0.922, respectively. When the time dimension was considered, the coefficient of Shaanxi increased to 0.984, Qinghai rose slightly to 0.923, while Gansu decreased to 0.939. This indicated that the impact of agro-economic expansion on ecosystem quality was affected by multiple factors, such as geography and time. This conclusion aligns with the findings of Chandio et al. [28]. The team took emerging economies in Asia as research samples and found that natural factors such as temperature and climate change significantly regulate the relationship between agricultural productivity and the ecological environment, providing evidence for the conclusion of regional heterogeneity in the study. However, this study further refined the sources of heterogeneity, clarifying three differentiated action paths: the combination of technological upgrading and industrial clusters in Shaanxi, water resource constraints in Gansu, and the single industrial structure in Qinghai, making up for the deficiency of existing studies in characterizing internal regional heterogeneity insufficiently. In addition, this study also examined the constraints of the ecological environment on agricultural development. When water resource utilization efficiency declined, Gansu experienced the largest drop in the proportions of cash crops and total agricultural output, decreasing by 31.12% and 26.75%, respectively. This is similar to the idea of the Kazungu K. F. group in exploring the restrictions of the ecological environment on sorghum production [29]. The group took sorghum production in Kenya as the research object and found that agricultural production in arid and semi-arid regions is significantly constrained by the ecological environment, which is consistent with the conclusion in this study that the quality of the ecological environment has a constraining effect on the agricultural economy. However, there are also differences between the two. Kazungu et al. [29] focused primarily on the production limitations of a single crop, while the research expands to the overall regional agricultural economy and quantifies the impact range of the decline in water resource utilization rate on the proportion of cash crops, the proportion of agricultural output value, etc., providing more accurate empirical support for the assessment of the intensity of ecological constraints.

For robustness testing, this study employed three estimation methods, including the method of moments, ridge regression, and ordinary least squares, to verify the regression results. It also replaced core variables to test the stability of the findings. This is similar to the idea of Zafeiriou et al. [30], who used multiple model estimation methods to verify the reliability of the results. Zafeiriou et al. [30] verified the stability of the impact of carbon emissions on the agricultural economy of 25 EU countries through chi-square tests, and this study enhanced the credibility of the conclusion through dual tests of multiple estimation methods and variable substitution. The difference lies in the fact that Zafeiriou et al. [30] focused on carbon emissions as a single ecological indicator, while the research integrates multi-dimensional indicators such as forest coverage rate, fertilizer application amount, and water resource utilization rate, depicting the interactive relationship between ecological environment quality and agricultural economy more comprehensively. In summary, the empirical analysis confirmed that agro-economic expansion and ecosystem quality in Northwest China had a bidirectional influence. The degree of influence was affected by factors such as geography and time. The experimental results supported all four hypotheses of this study, providing both theoretical and practical references for future related research.

5. Conclusion

To reveal the internal relationship between agro-economic expansion and ecosystem quality in Northwest China, this study focused on Shaanxi, Qinghai, and Gansu Provinces. Based on panel data from 2020 to 2023, the ARIMA model and TFE model were constructed to conduct an empirical analysis of the relationship between the two. The results showed that the current efficient and green-oriented agro-economic expansion in Northwest China contributed to improving ecosystem quality. The degree of impact was affected by factors such as geography and time. However, in some regions, the extensive development pattern partly damaged the ecological environment and restricted further agricultural economic growth. Based on these findings, several suggestions were put forward to address the problem of extensive agro-economic expansion and achieve the dual goals of sustainable agricultural growth and improved ecological quality in Northwest China. First, the green transformation of the agricultural economy should be promoted by region rather than through a uniform approach, ensuring the development model better matches ecological carrying capacity. Second, a regionally adaptive agro-economic expansion model should be established to reduce the heterogeneity constraints across different areas. Third, a long-term development mechanism should be built from the perspectives of technology, policy, and market to prevent a rebound of short-term extensive growth. Although this study achieved certain results in exploring the relationship between agro-economic expansion and ecosystem quality in Northwest China, it only revealed the internal connection between the two. The influence of intermediate variables such as agricultural production technology and policy intervention was not fully analyzed. Future research should examine the driving factors, intermediate variables, and ecological outcomes, and quantify the strength and efficiency of each link. This will help to clarify the specific pathways and mechanisms through which agro-economic expansion affects ecosystem quality.

6. Declarations

6.1. Data Availability Statement

The data presented in this study are available on request from the corresponding author.

6.2. Funding

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6.3. Institutional Review Board Statement

Not applicable.

6.4. Informed Consent Statement

Not applicable.

6.5. Declaration of Competing Interest

The author declares that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

7. References

- [1] Eytayo Raji, Tochukwu Ignatius Ijomah, & Osemeike Gloria Eyieyien. (2024). Integrating technology, market strategies, and strategic management in agricultural economics for enhanced productivity. *International Journal of Management & Entrepreneurship Research*, 6(7), 2112–2124. doi:10.51594/ijmer.v6i7.1260.
- [2] Olawale Adisa, Bamidele Segun Ilugbusi, Odunayo Adewunmi Adelekan, Onyeka Franca Asuzu, & Ndubuisi Leonard Ndubuisi. (2024). A comprehensive review of redefining agricultural economics for sustainable development: Overcoming challenges and seizing opportunities in a changing world. *World Journal of Advanced Research and Reviews*, 21(1), 2329–1241. doi:10.30574/wjarr.2024.21.1.0322.
- [3] Wuepper, D., Wiebecke, I., Meier, L., Vogelsanger, S., Bramato, S., Fürholz, A., & Finger, R. (2024). Agri-environmental policies from 1960 to 2022. *Nature Food*, 5(4), 323–331. doi:10.1038/s43016-024-00945-8.
- [4] Wang, Y., Liu, Y., Feng, W., & Zeng, S. (2023). Waste Haven Transfer and Poverty-Environment Trap: Evidence from EU. *Green and Low-Carbon Economy*, 1(1), 41–49. doi:10.47852/bonviewglce3202668.

- [5] Fatima, S., Abbas, S., Rebi, A., & Ying, Z. (2024). Sustainable forestry and environmental impacts: Assessing the economic, environmental, and social benefits of adopting sustainable agricultural practices. *Ecological Frontiers*, 44(6), 1119–1127. doi:10.1016/j.ecofro.2024.05.009.
- [6] Wu, G., Riaz, N., & Dong, R. (2023). China's agricultural ecological efficiency and spatial spillover effect. *Environment, Development and Sustainability*, 25(4), 3073–3098. doi:10.1007/s10668-022-02169-x.
- [7] Wang, J., Zhou, F., Xie, A., & Shi, J. (2024). Impacts of the integral development of agriculture and tourism on agricultural eco-efficiency: a case study of two river basins in China. *Environment, Development and Sustainability*, 26(1), 1701–1730. doi:10.1007/s10668-022-02781-x.
- [8] Sun, W., Yu, Q., Xu, C., Zhao, J., Wang, Y., & Miao, Y. (2024). Construction and optimization of ecological spatial network in typical mining cities of the Yellow River Basin: the case study of Shenmu City, Shaanxi. *Ecological Processes*, 13(1), 60–78. doi:10.1186/s13717-024-00539-z.
- [9] Li, Y., Cheng, W., Zuo, W., & Zhang, L. (2023). Agricultural Vulnerability to Drought in China's Agro-pastoral Ecotone: A Case Study of Yulin City, Shaanxi Province. *Chinese Geographical Science*, 33(5), 934–945. doi:10.1007/s11769-023-1386-5.
- [10] Wang, X., Xu, Y., Wang, H., Kang, M., Hua, J., & Wang, F. Y. (2024). Region-Farm Crop Planning Through Double Deep Q-Learning Toward Sustainable Agriculture. *IEEE Transactions on Computational Social Systems*, 11(6), 7608–7617. doi:10.1109/TCSS.2024.3441543.
- [11] Arumugam, U., & Manida, M. (2023). Agripreneurship for Sustainable Economic Development in India. *ComFin Research*, 11(4), 15–23. doi:10.34293/commerce.v11i4.6662.
- [12] Silvestri, C., Silvestri, L., Piccarozzi, M., & Ruggieri, A. (2024). Toward a framework for selecting indicators of measuring sustainability and circular economy in the agri-food sector: a systematic literature review. *International Journal of Life Cycle Assessment*, 29(8), 1446–1484. doi:10.1007/s11367-022-02032-1.
- [13] Maulidar, P., Fitriyani, F., Sasmita, N. R., Hardi, I., & Idroes, G. M. (2024). Exploring Indonesia's CO2 Emissions: The Impact of Agriculture, Economic Growth, Capital and Labor. *Grimsa Journal of Business and Economics Studies*, 1(1), 43–55. doi:10.61975/gjbes.v1i1.22.
- [14] Dong, J., Zhang, Z., Liu, B., & Zhang, X. (2023). Geographical exploration of the spatial differentiation mechanism of eco-environmental quality in northwest China from the perspective of "production-living-ecological" space. *Arid Land Geography*, 46(4), 515–526. doi:10.12118/j.issn.1000-6060.2022.242.
- [15] Xue, B., Han, B., Li, H., Gou, X., Yang, H., Thomas, H., & Stückrad, S. (2023). Understanding ecological civilization in China: From political context to science. *Ambio*, 52(12), 1895–1909. doi:10.1007/s13280-023-01897-2.
- [16] Liu, C., Huang, H., Melack, J. M., Tian, Y., Jiang, J., Fu, X., Cao, Z., & Wang, S. (2024). Assessing Land Degradation and Restoration in Eastern China Grasslands from 1985 to 2018 Using Multitemporal Landsat Data. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, 17, 19328–19342. doi:10.1109/JSTARS.2024.3483992.
- [17] Li, X., Hou, B., Zhang, R., & Liu, Y. (2023). A Review of RGB Image-Based Internet of Things in Smart Agriculture. *IEEE Sensors Journal*, 23(20), 24107–24122. doi:10.1109/JSEN.2023.3309774.
- [18] Duguma, A. L., & Bai, X. (2025). How the internet of things technology improves agricultural efficiency. *Artificial Intelligence Review*, 58(2), 63–88. doi:10.1007/s10462-024-11046-0.
- [19] Bai, M., Li, Z., Huo, P., Wang, J., & Li, Z. (2023). Propagation characteristics from meteorological drought to agricultural drought over the Heihe River Basin, Northwest China. *Journal of Arid Land*, 15(5), 523–544. doi:10.1007/s40333-023-0059-7.
- [20] Zhu, C. (2024). Spatial Distribution Characteristics and Influencing Factors of Geographical Indication Agricultural Products in Shaanxi Province. *International Journal of Global Economics and Management*, 3(1), 448–457. doi:10.62051/ijgem.v3n1.56.
- [21] Qiu, Y., Liu, C., Du, L., Jiang, X., & Yuan, D. (2024). Study on the safety of recycled water irrigation in arid, semiarid and underdeveloped areas: a case study in Qinghai Province. *Irrigation Science*, 42(4), 769–783. doi:10.1007/s00271-024-00918-6.
- [22] Liang, X., Li, J., Guo, G., Li, S., & Gong, Q. (2023). Urban water resource utilization efficiency based on SBM-undesirable-Gini coefficient-kernel density in Gansu Province, China. *Environment, Development and Sustainability*, 25(11), 13015–13034. doi:10.1007/s10668-022-02601-2.
- [23] El-Afifi, M. I., Eladl, A. A., Sedhom, B. E., & Hassan, M. A. (2025). Enhancing EV Charging Station Integration: A Hybrid ARIMA-LSTM Forecasting and Optimization Framework. *IEEE Transactions on Industry Applications*, 61(3), 4924–4935. doi:10.1109/TIA.2025.3540788.
- [24] Nasir, J., Aamir, M., Haq, Z. U., Khan, S., Amin, M. Y., & Naeem, M. (2023). A New Approach for Forecasting Crude Oil Prices Based on Stochastic and Deterministic Influences of LMD Using ARIMA and LSTM Models. *IEEE Access*, 11, 14322–14339. doi:10.1109/ACCESS.2023.3243232.

- [25] Arkhangelsky, D., Imbens, G. W., Lei, L., & Luo, X. (2024). Design-robust two-way fixed-effects regression for panel data. *Quantitative Economics*, 15(4), 999–1034. doi:10.3982/qe1962.
- [26] Raihan, A., Tanchangya, T., Rahman, J., & Ridwan, M. (2024). The Influence of Agriculture, Renewable Energy, International Trade, and Economic Growth on India's Environmental Sustainability. *Journal of Environmental and Energy Economics*, 3(1), 37–53. doi:10.56946/jeee.v3i1.324.
- [27] Hardi, I., Idroes, G. M., Zulham, T., Suriani, S., & Saputra, J. (2023). Economic Growth, Agriculture, Capital Formation and Greenhouse Gas Emissions in Indonesia: FMOLS, DOLS and CCR Applications. *Ekonomikalia Journal of Economics*, 1(2), 82–91. doi:10.60084/eje.v1i2.109.
- [28] Chandio, A. A., Gokmenoglu, K. K., Dash, D. P., Khan, I., Ahmad, F., & Jiang, Y. (2025). Exploring the energy-climate-agriculture (ECA) nexus: a roadmap toward agricultural sustainability in Asian countries. *Environment, Development and Sustainability*, 27(6), 12769–12795. doi:10.1007/s10668-023-04418-z.
- [29] Kazungu, F. K., Muindi, E. M., & Mulinge, J. M. (2023). Overview of Sorghum (*Sorghum bicolor* L), its Economic Importance, Ecological Requirements and Production Constraints in Kenya. *International Journal of Plant & Soil Science*, 35(1), 62–71. doi:10.9734/ijpss/2023/v35i12744.
- [30] Zafeiriou, E., Azam, M., & Garefalakis, A. (2023). Exploring environmental – economic performance linkages in EU agriculture: evidence from a panel cointegration framework. *Management of Environmental Quality: An International Journal*, 34(2), 469–491. doi:10.1108/MEQ-06-2022-0174.